

Welding Flux Cored Electrodes in N_2 - CO_2 and N_2 -Ar Atmospheres

With basic electrodes, weld deposits made in N_2 - CO_2 atmospheres contain less nitrogen at low nitrogen partial pressures than weld deposits made in N_2 -Ar atmospheres

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ABSTRACT. Results are reported on the relationship existing between the type of carrier gas used (CO_2 or Ar) and the absorption of nitrogen by ferritic flux cored electrode weld metal containing Mn, Si, and C. Specific emphasis was placed on a basic (CaF_2 - $CaCO_3$) flux cored electrode, although supportive data were obtained with rutile (TiO_2) base and experimental self-shielded electrodes.

For the basic electrode, deposits made in the N_2 - CO_2 atmosphere contained substantially less nitrogen at low nitrogen partial pressures than did those made in the N_2 -Ar atmosphere. This result is explained in terms of an increased tendency for CaF_2 to decompose in the CO_2 atmosphere. Further, when CO_2 was used as the carrier gas, a linear relationship was observed between the weld metal nitrogen concentration and the square root of the nitrogen partial pressure. At a given nitrogen partial pressure, the rutile base electrode yielded weld metal containing substantially more nitrogen than did the basic electrode. The self-shielding electrode was effective in reducing weld metal nitrogen concentrations.

The yield and tensile strengths of weld metal deposited using the basic electrode increased, and the impact values decreased with an increase in the weld metal nitrogen concentration.

Introduction

A number of authors have discussed the necessity of minimizing the amount of nitrogen in steel weld metal.¹⁻³ If the molten weld metal

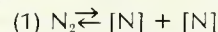
nitrogen level is not properly controlled, porous, unsatisfactory welds may result from nitrogen evolution upon solidification. This evolution is caused by the marked decrease in nitrogen solubility as the metal transforms from a liquid to a solid. In the case of flux cored electrode welding in the absence of an externally supplied shielding gas, provision must be made to decrease the partial pressure of nitrogen in the welding environment via the addition of gas forming agents to the flux. If this proves unsatisfactory, elements can be added which will react with the available nitrogen to form nitrides.⁴ The remaining, uncombined nitrogen will be dissolved in the metal, associated with dislocations, and/or precipitate as an iron nitride.⁵

This investigation was undertaken to determine the nature of interactions occurring between mixed N_2 - CO_2 atmospheres and flux cored weld metal. A N_2 - CO_2 atmosphere was chosen as it closely approximates that which would exist when welding with a self-shielded flux cored electrode containing carbonates as a flux constituent. Data on weld metal nitrogen levels were obtained as a function of nitrogen partial pressure for two electrodes. The first was a commercially available basic type containing CaF_2 and $CaCO_3$, and conforming to the

AWS E70T-5 classification. The second was an experimental self-shielded flux cored electrode containing no specifically introduced nitride formers. For comparison, data were also obtained in N_2 -Ar atmospheres. Further, the effect of nitrogen on the physical properties of some of these deposits was studied.

Nitrogen Solubility in Molten Iron

As discussed by Fast, the solution of N_2 in molten iron is dependent on the reaction:⁶



The reaction constant for this reaction is given by:

$$(2) K^1 = a_N^2/p(N_2)$$

where a_N is the activity of nitrogen in molten iron and $p(N_2)$ is the partial pressure of nitrogen. For small nitrogen concentrations, its activity is proportional to concentration; hence, eq. (2) becomes:

$$(3) K^{11} = [N]^2/p(N_2)$$

According to this equation, the quantity of nitrogen dissolved in a metal is proportional to the square root of the external nitrogen pressure:

$$(4) [N] = K^{11} p(N_2)^{1/2}$$

In agreement with this equation, the solubility of homonuclear diatomic gases (hydrogen, nitrogen and oxygen) in metals has been found experimentally to be proportional to the square root of the gas pressure when the solution concentrations are small.

Besides the pressure dependence of nitrogen solubility in molten iron, its dependence on temperature is also of interest.^{7,8} Pehlke and Elliott have

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Table 1—Welding Parameters

Voltage:	28 ± 1 V
Current:	325 ± 25 A
Extension:	1.25 ± 0.125 in. (31.75 ± 3.175 mm)
Travel speed:	12 ipm (30.5 cm/min)
Gas flow:	45 cfh (21.2 l/hr)
Electrode:	Positive

proposed the following relationship for the solubility of nitrogen in liquid iron at 1 atm pressure:

$$(5) [N] = 0.0565 \exp(-860/RT)$$

or:

$$(6) \log [N] = -1.248 - (188/T)$$

The solubility of nitrogen at 1 atm in iron at 1600 C (2912 F), as calculated from eq. (5) or (6), is then 0.045 wt-%.

Kunze, et al., studied the effect of a number of alloy additions on the solubility of nitrogen in molten steel. They proposed the equation:

$$(7) \log c(N_2, \text{ alloy}) = \frac{1}{2} \log p(N_2) -$$

$$1.290 - \frac{\Delta H^*}{4.575} \left(\frac{1}{T} - \frac{1}{3746} \right)$$

which requires a knowledge of ΔH^* as a composition dependent variable for prediction of nitrogen solubility under any condition. The authors give data on the effect of various alloy additions on ΔH^* .

Influence of the Welding Arc on Nitrogen Solubility

The previous discussion concerned the interaction of nitrogen with molten iron and steel in the absence of a welding arc. Based on results obtained with solid wires welded in N_2 -Ar atmospheres, Ludwig concludes that the chemical activity of nitrogen in an arc welding atmosphere is greater than that expressed by the square root law of gas solubility, eq. (4), with respect to nitrogen pressure.

The maximum solubility of nitrogen in molten iron as calculated using eq. (7) approaches 0.0565 wt-% as the temperature increases; whereas the nitrogen content of arc welds deposited from solid wires in air can be as high as 0.2 wt-%. It seems apparent, therefore, that during arc welding some additional factors operate to cause an increase in the nitrogen content. Wegrzyn and Apps state that when gaseous nitrogen occurs in both the atomic and diatomic forms simultaneously, a possibility in the welding arc, the concentration of nitrogen in iron will depend on the partial pressure of gases in the system Fe- N_2 -N; hence, eq. (4) must be modified to:

Table 2—Weld Metal Chemistry, %

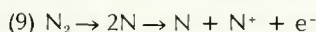
Electrode	N_2 atmosphere	$p(N_2)$, atm	$C^{(a)}$	5	P	Mn	Si	Al	Ti	O ₂	N ₂
Fluoride	N_2 -CO ₂	0.00	0.049	0.024	0.013	1.46	0.47	.01	.01	0.046	0.006
Fluoride	N_2 -CO ₂	0.05	0.048	0.026	0.014	1.43	0.45	.01	.01	0.051	0.013
Fluoride	N_2 -CO ₂	0.10	0.049	0.026	0.014	1.50	0.48	.01	.01	0.050	0.016
Fluoride	N_2 -CO ₂	0.15	0.047	0.025	0.014	1.54	0.49	.01	.01	0.050	0.022
Fluoride	N_2 -CO ₂	0.20	0.046	0.026	0.014	1.47	0.44	.01	.01	0.050	0.026
Fluoride	N_2 -CO ₂	0.25	0.048	0.026	0.014	1.49	0.44	.01	.01	0.046	0.026
Fluoride	N_2 -CO ₂	0.30	0.049	0.025	0.013	1.49	0.41	.01	.01	0.050	0.032
Fluoride	N_2 -CO ₂	0.35	0.046	0.025	0.013	1.50	0.41	.01	.01	0.057	0.033
Fluoride	N_2 -CO ₂	0.40	0.047	0.025	0.014	1.52	0.42	.01	.01	0.053	0.035
Fluoride	N_2 -CO ₂	0.50	0.047	0.020	0.013	1.51	0.41	.01	.01	0.065	0.040
Fluoride	N_2 -Ar	0.00	0.082	0.010	0.012	1.46	0.65	.01	.01	0.032	0.007
Fluoride	N_2 -Ar	0.05	0.082	0.010	0.013	1.44	0.63	.01	.01	0.036	0.024
Fluoride	N_2 -Ar	0.10	0.080	0.011	0.013	1.45	0.67	.01	.01	0.038	0.036
Fluoride	N_2 -Ar	0.20	0.080	0.010	0.012	1.47	0.65	.01	.01	0.039	0.044
Fluoride	N_2 -Ar	0.40	0.078	0.011	0.012	1.45	0.64	.01	.01	0.039	0.049
SSFC	N_2 -CO ₂	0.00	0.050	0.022	0.016	1.01	0.48	.01	.01	0.048	0.004
SSFC	N_2 -CO ₂	0.10	0.048	0.023	0.016	1.04	0.52	.01	.01	0.050	0.009
SSFC	N_2 -CO ₂	0.20	0.048	0.023	0.016	1.03	0.51	.01	.01	0.059	0.015
SSFC	N_2 -CO ₂	0.30	0.048	0.022	0.016	1.02	0.47	.01	.01	0.045	0.015
SSFC	N_2 -CO ₂	0.40	0.048	0.019	0.013	1.05	0.50	.01	.01	0.043	0.019
SSFC	N_2 -CO ₂	0.80	0.047	0.019	0.014	1.06	0.53	.01	.01	0.043	0.021
SSFC	Simulated air	0.80	0.048	0.018	0.014	1.06	0.51	.01	.01	0.043	0.022

^(a)In weight percent, wt-%

$$(8) [N] = k_1 p(N_2)^{1/2} + k_2 (p(N))$$

where $p(N)$ and $p(N_2)$ are the partial pressures of atomic and diatomic nitrogen, respectively.

As the solubility of atomic gases increases directly with partial pressure in comparison with diatomic gases, for which the solubility depends on the square root of partial pressure, the saturation of weld metal with nitrogen may be greater than that which would be experienced in the absence of the arc. Wegrzyn and Apps also conclude that the possibility of nitrogen solution in the form of cations via:

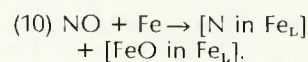


is improbable as the heat absorbed in this reaction would have to be inordinately high and, consequently, require temperatures difficult to obtain in the arc.

Lakowski and Grigorenko reported that atomic nitrogen does dissolve in the form of cations during welding.¹⁰ They divide the effect into "chemical" and "electrical" solution. Chemical solution occurs on the anode with the amount corresponding to the nitrogen solubility at a given temperature and partial pressure. Electrical solution results from the flow of positive ions to the cathode. Therefore, the total nitrogen content of weld metal is dependent on the cathode potential drop, welding current, temperature of the metal, and gas partial pressure.

It may also be pertinent to consider the relationship between gas composition and the absorption of nitrogen by molten weld metal. The effect of hydrogen in accelerating the rate of nitrogen absorption by iron has been

well documented.⁶ A similar role has been proposed for oxygen in a welding arc. The nitrogen content of weld metal deposited with stick electrodes in oxygen containing mixtures has been shown to be higher than would be predicted by a simple square root dependence. Wegrzyn and Apps conclude that this increase is related to the formation of nitric oxide (NO) in the arc, which occurs more easily than the formation of atomic nitrogen from N_2 dissociation. Nitric oxide contains one atom of nitrogen and is therefore readily soluble in liquid steel via the reaction:



Kobayashi, et al., studied the relationship between nitrogen solubility and the composition and pressure of gases as well as welding current and voltage.¹¹ They found that when welding was done in pure nitrogen atmospheres, the solubility was large at low pressures and was further increased by the presence of oxygen and other oxidizing gases.

Verhagen, et al., investigated the absorption of nitrogen by ferritic weld metal during gas shielded arc welding.¹² They concluded that the relationship between the weld metal nitrogen concentration and the partial pressure of nitrogen in the shielding atmosphere is dependent on the type of welding electrode used (flux cored or solid) and, in the case of flux cored electrode welding, the chemical composition of the flux.

Based on the results obtained with solid electrodes, the same authors also

concluded that the type of carrier gas used must be considered. Specifically, they noted that, when welding in N_2 - CO_2 atmospheres, as the CaF_2 content of a flux cored electrode is increased, the weld metal nitrogen level will decrease. At low nitrogen partial pressures using solid electrodes, Ar and, to a greater extent, Ar- O_2 gases give rise to higher nitrogen concentrations than CO_2 . In general, they observed pore formation when the weld metal nitrogen concentration reached approximately 0.03 wt-%. No results were reported on flux cored electrodes welded in N_2 -Ar atmospheres.

In this work, standard AWS multi-pass welds were made with a conventional arc welding gun in controlled N_2 - CO_2 atmospheres, using both a commercial basic type electrode containing $CaCO_3$ and CaF_2 , and designed to be used in CO_2 atmospheres, and an experimental self-shielded electrode. For comparison, the basic electrode was also run in a N_2 -Ar atmosphere. The welding parameters are listed in Table 1; chemical analyses of these deposits are given in Table 2.

The oxygen and nitrogen analyses were done with a Leco Model TC30 Nitrogen-Oxygen Determinator (fusion temperature approximately 2700 C). All other elements were done on an ARL Quantometer. In no case were nitride forming elements (Al, Ti, and Zr are examples) specifically added. Full size Charpy specimens and 0.505 in. (13 mm) tensile specimens were machined from selected samples. Impact data were obtained at 0, -20, and -50 F (-18, -29, and -46 C) from a number of the specimens. All tensile measurements were done at room temperature.

Nitrogen Absorption—Basic Electrode

Weld metal nitrogen concentration vs. the partial pressures of nitrogen in the welding atmosphere are plotted in Fig. 1. At low nitrogen partial pressures, deposits made in the N_2 -Ar atmosphere contained substantially more nitrogen than those made in the N_2 - CO_2 atmosphere. These data were further verified by X-ray images of beads on plate. Porosity was observed in weld metal deposited in the N_2 -Ar atmosphere when the nitrogen partial pressure exceeded 0.1 atm (0.035 wt-% N_2 in the metal).

Nitrogen partial pressures in excess of 0.35 atm (0.033 wt-% N_2 in the metal) were required to initiate porosity in the N_2 - CO_2 atmosphere. Schiguchi and Masumoto obtained similar results for solid wires welded in CO_2 and Ar atmospheres.¹³ Figure 2 is a plot of the weld metal nitrogen concentra-

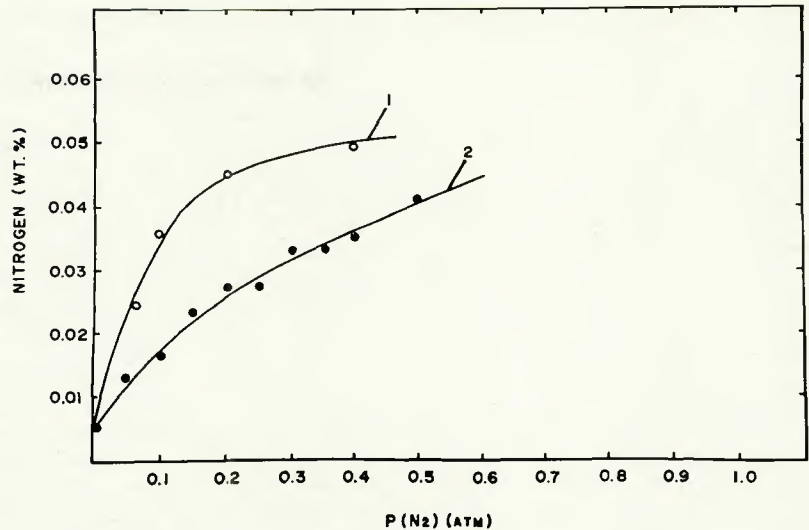


Fig. 1—Nitrogen concentration in the weld metal vs. the partial pressure of nitrogen in the shielding atmosphere for a basic flux cored electrode: 1—Ar; 2— CO_2

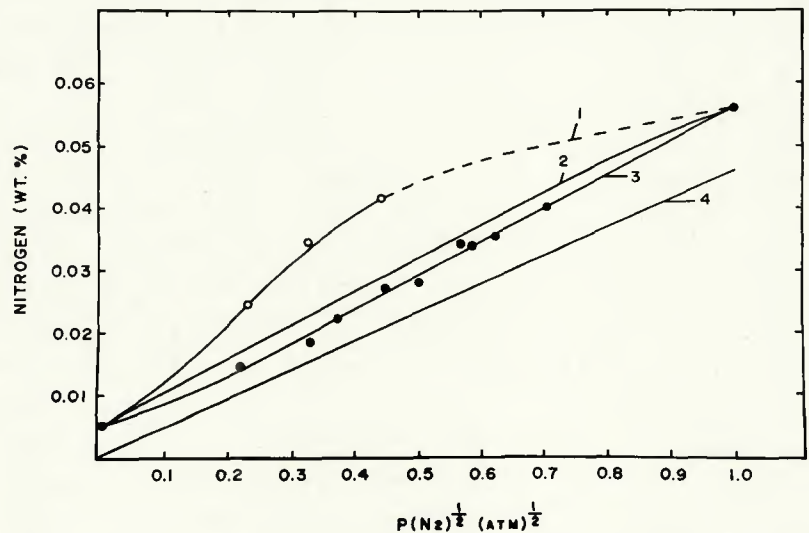
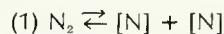


Fig. 2—Nitrogen concentration in the weld metal vs. the square root of the nitrogen partial pressure (basic electrode): 1—Ar; 2— $CO + O_2$; 3— CO_2 ; 4—equilibrium nitrogen concentration of molten iron at 1600 C (2912 F)⁷

tion versus the square root of the nitrogen partial pressure [$p(N_2)^{1/2}$]. A linear curve would indicate that the reaction occurring between the atmospheric nitrogen and the weld metal obeyed eq. (4). This was approximately the case for weld metal deposited under N_2 - CO_2 ; however, when depositions were carried out under the N_2 -Ar atmosphere, significantly higher levels of nitrogen were obtained, at low nitrogen partial pressures, than would be allowed by a reaction obeying



Similar results have been reported by Ludwig and Kaplan and Hill for solid and flux cored wires, respectively, welded in N_2 -Ar atmospheres.

Included in Fig. 2 is a plot of the equilibrium nitrogen content of mol-

ten iron at 1600 C (2912 F) calculated from eq. (5). The effect of alloy additions on the solubility of nitrogen, as calculated with eq. (9), proved, in this case, to be insignificant. It is interesting to note that eq. (5) predicts that as the temperature increases the equilibrium nitrogen concentration approached 0.0565 wt-%. The same value is obtained when this electrode is welded under 1 atm of nitrogen.

Two additional points should be made about Figure 2. First, the curve obtained in the N_2 -Ar atmosphere is possibly affected by the presence of CO_2 from the $CaCO_3$ present in the flux. Further, since CO_2 decomposes at relatively low temperatures to yield CO and O_2 , the carrier gas probably contains CO_2 , CO , and O_2 . For the particular flux cored electrode used in this work, the maximum possible CO_2

addition based on the decomposition of CaCO_3 is approximately 1.0%. It is difficult to determine how much of this is decomposed to CO and O_2 in the welding arc.

The second point follows from the first. The curve obtained when CO_2 is used as the carrier gas should probably be modified to take into account the decomposition of CO_2 . This has been done in Fig. 2. Curve 3 in Fig. 2 results if no CO_2 decomposition is considered. Curve 2 is obtained if the gas mixture is assumed to be $\text{N}_2\text{-CO-O}_2$. The net result is that the effective partial pressure of nitrogen is reduced below the value obtained if no CO_2 decomposition is considered.

The data obtained in the Ar atmosphere indicate that there is little difference between this basic flux cored electrode and solid electrodes with respect to the absorption of nitrogen from the shielding atmosphere. In both cases, nitrogen absorption at low nitrogen partial pressures is significantly higher than would be predicted from eq. (4). This behavior has been discussed by a number of investigators.²⁻⁴ Apparently, in atmospheres containing substantial amounts of Ar, the CaF_2 in the flux does not have a major effect on reducing the nitrogen content of weld metal.

This result is somewhat surprising. Verhagen, et al., welded with solid electrodes in an atmosphere com-

posed of Ar + 5% Cl_2 and noted a marked decrease in the amount of nitrogen absorbed by the deposit. They further reported that there is little difference between the absorption curve obtained in the Ar- Cl_2 atmosphere and the curve representing the nitrogen content of pure iron as a function of the partial molecular nitrogen pressure at 1600 C (2912 F) without a welding arc. This result was attributed to a possible decrease in arc temperature resulting from the presence of Cl_2 in the arc.

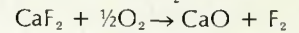
A decrease in arc temperature would result in a decrease in the amount of dissociated nitrogen—and hence, a decrease in the weld metal nitrogen concentration at low nitrogen partial pressures. Apparently, in this work, the CaF_2 present in the flux does not significantly dissociate in the Ar atmosphere to yield F_2 . It is assumed that Cl_2 and F_2 would behave in a similar fashion. It should also be pointed out that the presence of a slag cover, in this instance, had little effect on nitrogen absorption.

The results obtained when CO_2 was used as the carrier gas were, to some extent, similar to those reported for solid electrodes welded in CO_2 at low nitrogen partial pressures. Here, however, the similarity ends. For solid electrodes, as the $\text{N}_2\text{-CO}_2$ ratio is increased, the weld metal nitrogen concentration continues to increase, eventually overtaking concentrations

obtained in $\text{N}_2\text{-Ar}$ atmospheres at the same nitrogen partial pressure.

Apparently, CaF_2 is more effective in reducing the weld metal nitrogen concentration when CO_2 is used as a carrier gas than when Ar is used. One possible explanation for this result may be that the presence of decomposable flux constituents, together with the CO_2 atmosphere, results in a marked decrease in the arc temperature or arc length and, hence, decrease in the amount of dissociated nitrogen in the arc. If this were entirely true, however, one would expect a similar decrease in the weld metal nitrogen concentration when depositions are carried out in $\text{N}_2\text{-Ar}$ mixtures when compared to solid electrodes welded under the same condition. This was not the case.

It is possible that, when basic flux cored electrodes are used, the presence of oxygen is indirectly beneficial in decreasing nitrogen absorption. The only way that F_2 could enter the Ar arc is via the direct dissociation of CaF_2 to Ca and F_2 . Because of the large amount of energy required to initiate this reaction, only small amounts of F_2 would result. In the CO_2 atmosphere, substantial amounts of oxygen would theoretically be available due to the decomposition of CO_2 . The oxygen could react with CaF_2 as follows:



This reaction requires considerably less energy to initiate than does the

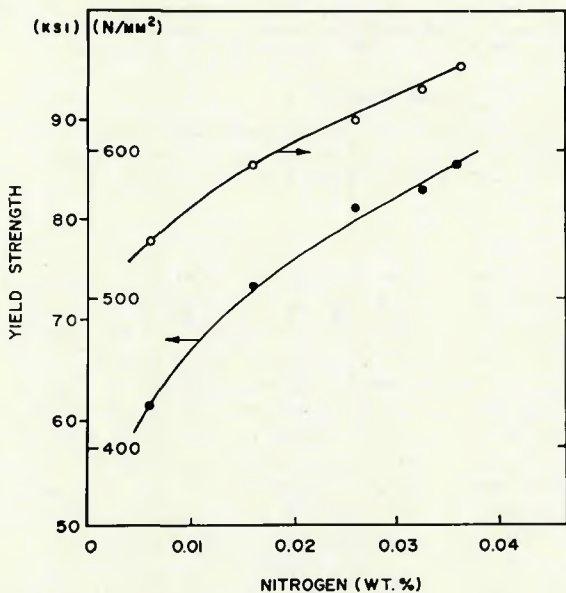


Fig. 3—Tensile and yield strengths of deposits made with the basic flux cored electrode in $\text{N}_2\text{-CO}_2$ atmosphere vs. the weld metal nitrogen concentration

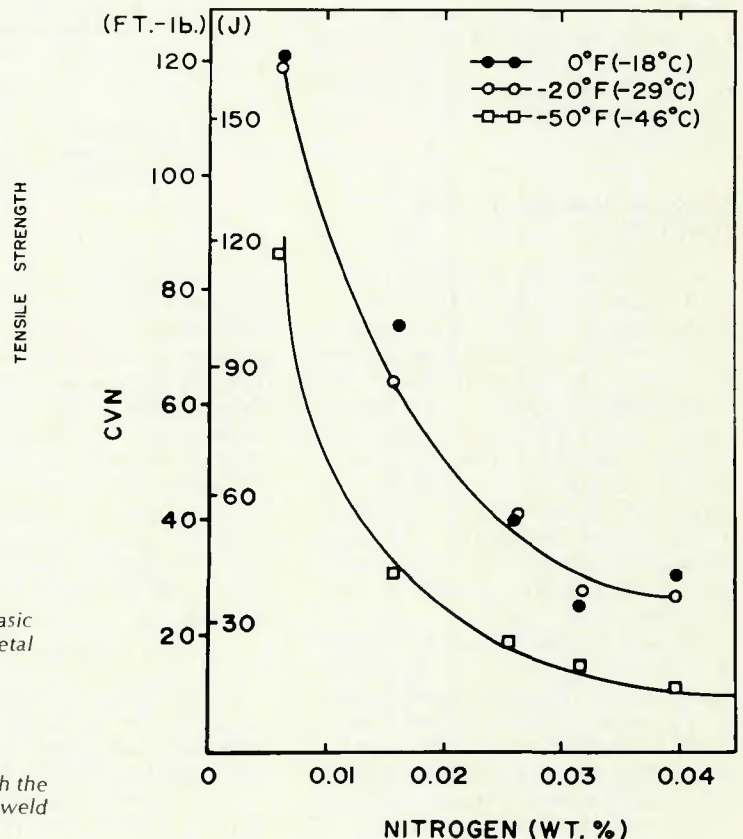


Fig. 4 (right)—Charpy V-notch toughness of deposits made with the basic flux cored electrode in $\text{N}_2\text{-CO}_2$ atmospheres vs. the weld metal nitrogen concentration

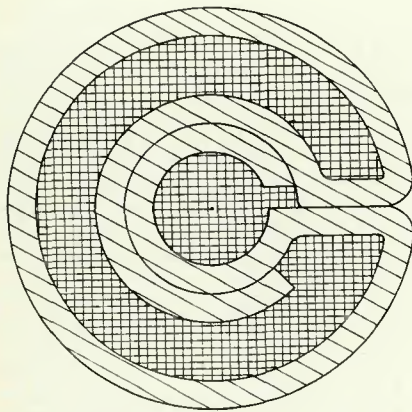


Fig. 5—Schematic representation of the cross-section of an experimental self shielded flux cored electrode

direct decomposition of CaF_2 . It is interesting to note that the nitrogen absorption curve (Fig. 1) obtained when this basic flux cored electrode was welded in N_2 - CO_2 atmospheres is almost identical to that obtained by Verhagen, et al., for solid electrodes welded in $\text{Ar} + 5\% \text{Cl}_2$.

A rutile (TiO_2) based electrode welded in an atmosphere consisting of 0.2 atm of N_2 and 0.8 atm of CO_2 yielded weld metal containing 0.063 wt-% N_2 . Weld metal deposited from the fluoride based electrode in the same atmosphere contained only 0.026 wt-% N_2 . This result further emphasizes the positive effect of fluoride in reducing the absorption of nitrogen by weld metal.

Effect of Nitrogen on Physical Properties

As shown in Fig. 3, the tensile and yield strengths of deposits made in the N_2 - CO_2 atmosphere increased with increasing concentrations of nitrogen in the weld metal. It is difficult to determine with any degree of certainty the manner in which the nitrogen is distributed in these deposits. Under equilibrium conditions, the maximum amount of nitrogen that can remain in solid solution in pure iron is approximately 0.012 wt-%.

As can be seen in Fig. 1, quantities substantially in excess of this amount are retained in weld deposits. Indeed, pore free deposits were obtained when the nitrogen content exceeded 0.03 wt-%. As discussed by other investigators, the rapid decrease occurring in the rate of diffusion of nitrogen in the weld metal as the metal solidifies precludes the attainment of equilibrium.¹² As such, the nitrogen can occur in the weld deposit in any of the following states:⁹

1. Dissolved in the lattice of iron.
2. Bound to dislocations.
3. fcc nitride Fe_3N (γ).

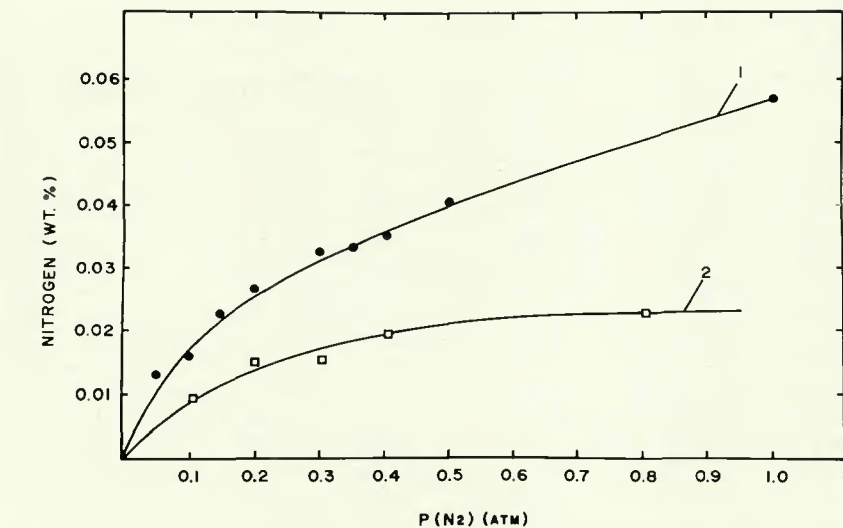


Fig. 6—Nitrogen concentration in the weld metal vs. the partial pressure of nitrogen in a N_2 - CO_2 atmosphere: 1—basic electrode; 2—self shielded electrode

4. Complex bct nitride Fe_3N or Fe_{16}N_2

5. Combined with elements like aluminum, silicon and vanadium.

The increase observed in the tensile and yield strengths (Fig. 3) and the decrease in the impact values (Fig. 4) may have been due to the fact that a substantial amount of the nitrogen present in these deposits did not react to form a nitride on cooling, but rather remained in super saturation and/or bound to dislocations. Since the bond energy of nitrogen to a dislocation is approximately 0.75 eV as compared to 0.25 to 0.35 eV in a nitride, this conclusion is not surprising.

Self Shielded Flux Cored Electrode

The results obtained when the basic

flux cored electrode was welded in CO_2 atmospheres indicate that, providing a proper ratio of CaF_2 to CaCO_3 is achieved, it may be possible to formulate a flux cored electrode which could be successfully operated without an external gas shield. Further, if a sufficient amount of CO_2 is generated when the CaCO_3 decomposes, no nitride forming elements will be required.

A cross-sectional view of such an electrode is shown in Fig. 5. The electrode possesses a dual-tube configuration and, hence, is somewhat similar to a covered electrode. As shown by the weld metal chemistries of deposits made with this electrode (Table 2), no specifically introduced nitride formers were present. The weld metal nitrogen concentration obtained when this electrode was welded in N_2 - CO_2

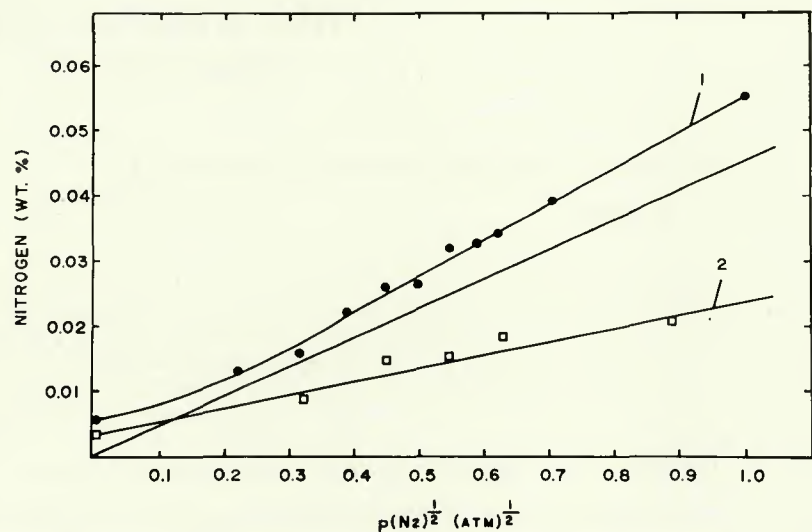


Fig. 7—Nitrogen concentration in the weld metal vs. the square root of the nitrogen partial pressure in a N_2 - CO_2 atmosphere: 1—basic electrode; 2—self shielded electrode. Solid curve represents equilibrium nitrogen concentration of molten iron 1600 C (2912 F)⁷

atmospheres is plotted vs. $p(N_2)$ and $p(N_2)^{1/2}$, respectively, in Figs. 6 and 7.

The data obtained when the basic electrode was welded under the same conditions has been included in Figs. 6 and 7 for comparison. It can be seen that the self shielded electrode was effective in decreasing the nitrogen partial pressure in the arc environment. Under an external nitrogen partial pressure of 0.8 atm, using either simulated air or N_2-CO_2 , deposits made with this electrode contained approximately 0.021 wt-% nitrogen. Under identical conditions, the basic type electrode yielded weld metal containing 0.049 wt-% nitrogen.

Molten iron at 1600 C (2912 F) in equilibrium with 0.8 atm of nitrogen would contain approximately 0.040 wt-%. When the weld metal nitrogen concentration is plotted vs. the square root of the nitrogen partial pressure (Fig. 7), the resulting curve is almost linear for both the basic and dual-tube electrodes. Thus, little nitrogen dissociation occurs.

Conclusions

1. At a fixed nitrogen partial pressure, basic flux cored electrodes absorb substantially less nitrogen when CO_2 is used as a carrier gas than when Ar is used.

2. In N_2-CO_2 atmospheres, the absorption of nitrogen by this basic flux cored electrode obeys the square root law of gas solubility.

3. Porosity is not observed until the weld metal nitrogen concentration exceeds approximately 0.03 wt-%.

4. When CO_2 is used as a shielding gas, CaF_2 protects weld metal from atmospheric nitrogen. This protection is most probably due to a decrease in arc temperature brought about by the presence of fluorine.

5. In a predominantly CO_2 atmosphere, rutile base flux cored electrodes are more sensitive to atmospheric nitrogen than are basic electrodes.

6. The yield and tensile strengths increase, and the impact values decrease as the weld metal nitrogen concentration increases.

7. It is possible to fabricate a flux cored electrode which can be operated without an external gas shield and which contains no specifically added nitride forming elements.

Acknowledgments

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References

1. Smith, D. C., and Johannes, K. P., "Development Of A Notch-Tough Self-Shielded Flux-Cored Electrode," *Welding Journal*, 47 (3), March 1968, pp. 207 to 214.
2. Oyler, G. W., and Stout, R. D., "Porosity In The Welding Of Carbon Steel," *Welding Journal*, 32 (9), September 1953, Res. Suppl., pp. 454-s to 460-s.

3. Ludwig, H. C., "Nitrogen Effects In Argon Arc Welding Atmospheres," *Welding Journal*, 34 (9), September 1955, Res. Suppl., pp. 409-s to 414-s.

4. Kaplan, H. I., and Hill, D. C., "Thermodynamics Of Air-Operating Flux Cored Electrodes And An Analysis Of Weld Metal Toughness," *Welding Journal*, 55 (1), January 1976, Res. Suppl., pp. 13-s to 19-s.

5. Kumar, R., *Physical Metallurgy Of Iron And Steel*, Asia Publishing House, New York, 1968, 456 pp.

6. Fast, J. D., *Interaction Of Metals And Gases*, Vol. 1, Academic Press, New York, 1965, 300 pp.

7. Kunze, H. D., Schurmann, E., and Parlee, N. A. D., "Influence Of Temperature And Equivalent Effect Of Added Elements On The Solubility, Activity, And Activity Coefficient Of Nitrogen In Liquid Iron," *Metallurgical Transactions*, 1 (1), 1970, pp. 281 to 290.

8. Pehlke, R. D., and Elliott, J. F., "Solubility Of Nitrogen In Liquid Iron Alloys. 1. Thermodynamics," *Trans. AIME*, 208 (12), 1960, pp. 1088 to 1101.

9. Wegrzyn, J., and Apps, R. L., "The Influence Of Nitrogen On The Properties Of Mild Steel Weld Metal Deposited From Covered Electrodes," *College Of Aeronautics Cranfield*, CoA Report Mat. No. 4, 1965, 30 pp.

10. Lakowski, V. J., and Grigorenko, G. M., *Awtom. Swarka*, 11, 1964.

11. Kobayashi, T., Kuwana, T., and Kikuchi, U., "Arc Atmosphere And Nitrogen Content Of Weld Metal," *Welding In The World*, 5 (2), 1967, pp. 58 to 73.

12. Verhagen, J. G., den Ouden, G., Liefkens, A., and Tichelaar, G. W., "Nitrogen Absorption By Ferritic Weld Metal During Arc Welding," *Metal Construction And British Welding Journal*, (4), 1970, pp. 135 to 154.

13. Sekiguchi, H., and Masumoto, I., *J. Jap. Weld. Soc.*, 28, 1959, pp. 463 to 468.

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Hot Wire Welding and Surfacing Techniques

by A. F. Manz

This WRC Bulletin is divided into two parts. The first part presents a non-mathematical description of the Hot Wire processes and their general characteristics. The second part presents a generalized in-depth mathematical treatment of electrode melt rate phenomena. In addition to describing Hot Wire electrode melting, Part II also presents considerable information concerning the general case of I-R heating of any moving electrode. Examples are given to demonstrate the utility of the derived equations in predicting the melt rates, temperature distribution and voltage drops of moving electrodes. Specific examples concerning Hot Wires are included.

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